Journal of Wildlife Management 74(3):479–488; 2010; DOI: 10.2193/2008-539

Management and Conservation Article

Changes in Agriculture and Abundance of Snow Geese Affect Carrying Capacity of Sandhill Cranes in Nebraska

AARON T. PEARSE,[1] *United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA*

GARY L. KRAPU, *United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA*

DAVID A. BRANDT, *United States Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, ND 58401, USA*

PAUL J. KINZEL, *United States Geological Survey, Geomorphology and Sediment Transport Laboratory, 4620 Technology Drive, Suite 400, Golden, CO 80403, USA*

ABSTRACT The central Platte River valley (CPRV) in Nebraska, USA, is a key spring-staging area for approximately 80% of the midcontinent population of sandhill cranes (*Grus canadensis*; hereafter cranes). Evidence that staging cranes acquired less lipid reserves during the 1990s compared to the late 1970s and increases in use of the CPRV by snow geese (*Chen caerulescens*) prompted us to investigate availability of waste corn and quantify spatial and temporal patterns of crane and waterfowl use of the region. We developed a predictive model to assess impacts of changes in availability of corn and snow goose abundance under past, present, and potential future conditions. Over a hypothetical 60-day staging period, predicted energy demand of cranes and waterfowl increased 87% between the late 1970s and 1998–2007, primarily because peak abundances of snow geese increased by 650,000 and cranes by 110,000. Compared to spring 1979, corn available when cranes arrived was 20% less in 1998 and 68% less in 1999; consequently, the area of cornfields required to meet crane needs increased from 14,464 ha in 1979 to 32,751 ha in 1998 and 90,559 ha in 1999. Using a pooled estimate of 88 kg/ha from springs 1998–1999 and 2005–2007, the area of cornfields needed to supply food requirements of cranes and waterfowl increased to 65,587 ha and was greatest in the eastern region of the CPRV, where an estimated 54% of cranes, 47% of Canada geese (*Branta canadensis*), 45% of greater white-fronted geese (*Anser albifrons*), and 46% of snow geese occurred during ground surveys. We estimated that a future reduction of 25% in available corn or cornfields would increase daily foraging flight distances of cranes by 27–38%. Crane use and ability of cranes to store lipid reserves in the CPRV could be reduced substantially if flight distance required to locate adequate corn exceeded a physiological maximum distance cranes could fly in search of food. Options to increase carrying capacity for cranes include increasing accessibility of cornfields by restoring degraded river channels to disperse roosting cranes and increasing wetland availability in the Rainwater Basin to attract snow geese using the CPRV.

KEY WORDS agriculture, corn, *Grus canadensis*, Nebraska, Platte River, sandhill cranes, spring migration, waterfowl.

Agricultural lands in the United States are a major source of food for migratory birds. In the central Platte River valley (CPRV) of Nebraska, USA, corn provides virtually all of the maintenance and productive energy required by >0.5 million sandhill cranes (*Grus canadensis*; hereafter cranes) of the midcontinent population during late winter and early spring (Reinecke and Krapu 1986, Kinzel et al. 2006). In the late 1970s, waste corn exceeded estimated energetic needs, and cranes acquired an average 400 g of lipid reserves while staging in the CPRV (Krapu et al. 1985, Reinecke and Krapu 1986). Waterfowl including greater white-fronted geese (*Anser albifrons*; hereafter white-fronted geese) and Canada geese (*Branta canadensis*) also used the CPRV during spring and relied primarily on corn for their energy needs, including deposition of lipid reserves (U.S. Fish and Wildlife Service [USFWS] 1981, Krapu et al. 1995).

During the 1990s, cranes flew farther from nocturnal roosts in the Platte River to feed than during the 1970s and rates of lipid storage decreased (G. L. Krapu, United States Geological Survey [USGS], unpublished data). The likely causes for this change include increased competition with waterfowl for grain, improvements in harvest efficiency, and fewer acres planted to corn (Krapu et al. 2004, 2005). The population of snow geese (*Chen caerulescens*) increased from being uncommon in the CPRV during the 1970s (USFWS 1981) to abundant by the late 1990s (Abraham et al. 2005, Vrtiska and Sullivan 2009). Similar to cranes, snow geese rely on corn to meet most energy requirements (Alisauskas and Ankney 1992). These factors and an estimated increase of approximately 110,000 cranes in the CPRV from 1982 to 2001–2003 (Sharp and Vogel 1992, Kinzel et al. 2006) suggested that demand for corn has increased and may have exceeded supply.

Because of the key role of the CPRV in the annual cycle of midcontinent cranes, managers need detailed information regarding how landscape-level changes in agriculture and distribution and abundance of cranes and waterfowl affect the capacity of the CPRV to sustain spring-staging populations. This information is required to develop a predictive model that will notify managers of situations when cranes may no longer be able to meet energetic needs and provide guidance for management. Our objectives were to 1) estimate corn in the CPRV during spring at crane arrival and departure, 2) quantify spatial and temporal patterns of crane and waterfowl use of the region, and 3) develop a model that relates energy demand of cranes and other migratory birds to energy available from corn. We used this model to compare past and current status of food availability and construct future scenarios representing decreases in corn availability and cornfield area and increased competition from snow geese.

[1] *E-mail: apearse@usgs.gov*

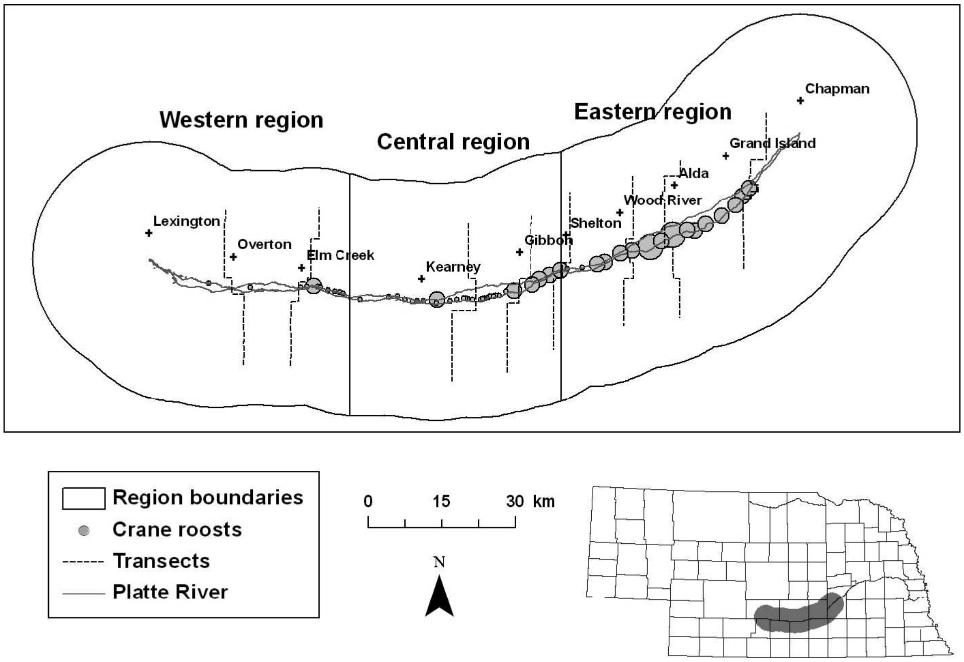

Figure 1. Boundaries used to divide the central Platte River valley in south-central Nebraska, USA, into 3 regions of study for modeling energetics of sandhill cranes and waterfowl during spring migration, 1998–2007. Locations of crane roosts and their relative sizes derived from remote videography during spring 2005 by Kinzel et al. (2006).

STUDY AREA

The CPRV is a corridor of land bounding the Platte River in south-central Nebraska. We focused modeling efforts on the portion of the CPRV known as the Big Bend Reach between Lexington and Chapman, Nebraska, where virtually all crane use occurred in the CPRV (Krapu et al. 1982, Kinzel et al. 2006; Fig. 1). The Platte River in this reach was characterized by braided channels and a shifting streambed, and has been previously described (USFWS 1981). Land use of the CPRV was dominated by agriculture, primarily row crops, including corn and soybeans. Cranes used river channels as nocturnal roost sites, nearby cornfields to feed on corn, and meadows mainly to feed on invertebrates (Krapu et al. 1982, Reinecke and Krapu 1986).

METHODS

Corn Availability

Reinecke and Krapu (1986) selected 30 quarter sections (65 ha) at random in the CPRV during spring 1979 for sampling corn. Krapu et al. (2004) resampled 23 of the original quarter sections during falls 1997 and 1998. During the following springs, we estimated corn on the same quarter sections as cranes began to arrive during mid-February and at their departure during mid-April 1998–1999. Based on sampling methods described by Krapu et al. (2004), we selected 3–6 main plots (40.4 m^2) at random within each field depending on field size and located 2 subplots (4.1 m^2) within each main plot (Frederick et al. 1984). We collected all corn from subplots (i.e., individual kernels and ears) and only corn ears from the main plot. We dried recovered corn to a constant mass and weighed it to the nearest 0.1 g.

We determined mass of corn (kg/ha) at sampled plots by summing the amount from ears and the estimated mass of individual kernels sampled in subplots. We used a cluster sample design to estimate year-specific mean corn availability, where cornfields represented primary sample units and sampled plots within fields represented secondary sample units (Lohr 1999). We calculated sample weights of corn plots as the inverse of the product of the probability of selection of primary and secondary sample units (Stafford et al. 2006). We incorporated these weights and the clustered design into the SURVEYMEANS procedure to estimate mean corn availability (SAS Institute, Inc., Cary, NC).

We obtained spatial data for croplands in Nebraska during 2002–2007 to determine the proportion of the study area in corn production (National Agricultural Statistics Service 2002–2007). We used a buffer distance of 3.7 km (114,100 ha) around the main channel of the Platte River as our area of interest based on the average half-width of the study area used in previous research (Krapu et al. 1984). We calculated the annual proportion of cornfields in the study area and compared this value with past estimates in Reinecke and Krapu (1986).

Sandhill Crane and Waterfowl Surveys

We established 8 transects in the CPRV (Fig. 1; Krapu et al. 2005) to estimate distances cranes foraged from the river, temporal use of the CPRV by cranes, spatial distribution of waterfowl, and abundances of waterfowl. We conducted ground surveys each week on Tuesdays beginning the third week of February and continuing through the second week

Table 1. Individual and population parameters we used in contemporary and future models of energetics of sandhill cranes and waterfowl during spring migration in the central Platte River valley, Nebraska, USA, 1998–2007.

Species or group	Body wt[a]	Body mass gain (g/day)	Abundance[b]	Residence time (days)	Arrival date	Study area region		
						% western	% central	% eastern
Sandhill crane			510,000[c]	–[d]	15 Feb	8[c]	38[c]	54[c]
Lesser F	3.3[e]	12.6[e]	163,200[f]	–[d]	15 Feb	12	46	42
Lesser M	3.8[e]	16.2[e]	163,200[f]	–[d]	15 Feb	12	46	42
Greater F	3.9[e]	15.6[f]	91,800[f]	–[d]	15 Feb	2	22	76
Greater M	4.5[e]	11.7[e]	91,800[f]	–[d]	15 Feb	2	22	76
Canada goose	2.7[g]	0	185,000	28	22 Feb	30	23	47
Greater white-fronted goose	2.4[h]	0[h]	33,000	14	9 Mar	19	36	45
Snow goose	2.2[h]	0[h]	650,000	14	2 Mar	26	28	46
Northern pintail	0.9[h]	4.0[h]	9,000	21	2 Mar	25	51	24
Mallard	1.2[g]	4.0	30,000	21	2 Mar	37	40	23

[a] Average body wt (kg).
[b] Peak abundance.
[c] Kinzel et al. (2006).
[d] Model based.
[e] Models of mass gain (kg) based on G. L. Krapu, United States Geological Survey, unpublished data.
[f] Based on 64:36 ratio of lesser to greater sandhill cranes and 50:50 sex ratio.
[g] Bellrose (1980).
[h] R. R. Cox, Jr., United States Geological Survey, unpublished data.

of April 1998–2002. Each transect extended 16.1 km north and south from the main channel of the Platte River and was 440 m on each side of maintained roads (2,834 ha/transect; Fig. 1). Beginning at 0800 hours, a field technician drove the survey route, enumerated cranes and waterfowl in each transect, and recorded their distance from the river channel. We estimated abundance of waterfowl by extrapolating mean densities estimated from surveys to the entire area of interest (i.e., 16.1-km buffer surrounding the river reach). We obtained locations of roosting cranes from aerial infrared videography (Kinzel et al. 2006) and used these data to determine spatial distribution of cranes among regions.

Population Energetics Model

We developed a daily ration model for cranes and selected populations of waterfowl during spring migration. This type of bioenergetic model has been used as a conservation planning tool for several species (e.g., Reinecke and Loesch 1996, Wiens and Farmer 1996, Miller and Newton 1999) and, although more sophisticated types of foraging models exist, daily ration models are robust under a wide range of conditions (Goss-Custard et al. 2003). Our primary objective was to quantify energy requirements of staging cranes and an assemblage of other migratory birds that potentially compete with cranes for food in the CPRV. We assumed cranes and waterfowl used corn as a primary source of energy (Reinecke and Krapu 1986, Krapu et al. 1995), and we converted bird energy needs into biomass of corn necessary to supply demands. We defined 15 February–15 April as the time period of interest based on phenology of crane migration (USFWS 1981). Due to variation in energy requirements, we calculated individual and population energy demands daily and summed them across species and days to quantify total energy demand. We delineated regions within the study area to evaluate spatial heterogeneity in energy supply and demand. We used 2 regions delineated by Krapu et al. (1984, fig. 1) and availability of corn from data reported previously by Reinecke and Krapu (1986) for our historical model. We divided the study area into 3 regions (Fig. 1) and used a combination of field sampling and remotely sensed data to quantify mean availability of corn and area of cornfields within regions for our contemporary model.

Energy requirements.—We estimated the daily energy expenditure of an individual crane as a function of basal metabolic rate (BMR), cost of free living, cost of foraging flights, and cost of lipid production. We calculated BMR from an allometric relationship for all birds (Reynolds and Lee 1996). Because body mass varied by sex and subspecies (i.e., lesser sandhill cranes [*Grus canadensis canadensis*] and greater sandhill cranes [*G. c. tabida*]; subspecies based on mtDNA; Jones et al. 2005; Table 1), we modeled energy needs separately for each group. To approximate cost of free living, we multiplied BMR × 2. During their stay in the CPRV, cranes generally used the Platte River channel for roosting, made 1–2 feeding trips per day to cornfields, and spent midday in pastures with ponds (Krapu et al. 1984, Reinecke and Krapu 1986). We calculated the daily cost of flight as a function of the cost per unit time (Norberg 1996, eq 7.35), a flight speed of 43 km/hour (i.e., median value reported by Tacha et al. 1992), and the distance our model predicted cranes must travel from the river to foraging sites on the previous day. Overall flight time accounted for departure and return to roost sites, one additional flight for movements between foraging bouts, and a fixed time of 2 minutes per flight for takeoff and landing. We added this energy cost to daily energy expenditure and allowed it to vary with body mass of cranes. Distance flown was set at 1.8 km per one-way trip for cranes in the late 1970s (USFWS 1981), and we allowed it to vary spatially and temporally in contemporary and future scenarios. We set the cost of lipid production as 12.7 kcal/g, which was the energy

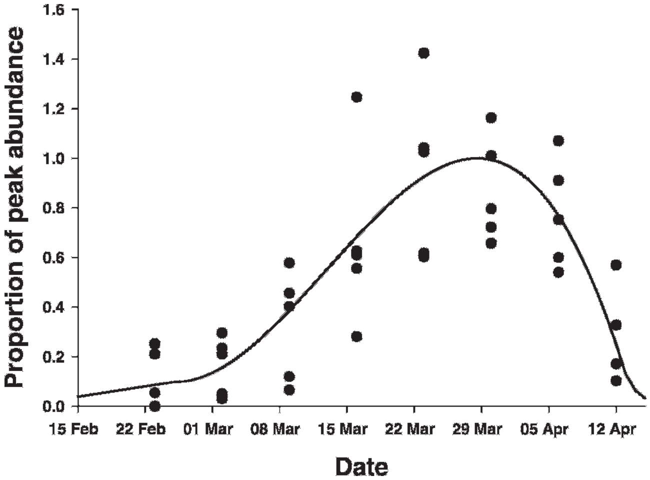

Figure 2. Proportion of peak population indices of sandhill cranes estimated from weekly ground transects during springs 1998–2002 in the central Platte River valley of Nebraska, USA. Predicted proportion during survey period estimated from a third-order polynomial regression, where $y = 19.1 - 0.86(date) + 0.013(date^2) - 0.00006(date^3)$.

content of lipids (9.85 kcal/g; Kendeigh et al. 1977) adjusted by the estimated metabolic efficiency for producing lipids (75%; Walsberg 1983).

We sampled transects for 7–8 weekly surveys during springs 1998–2002. We estimated crane population indices as a third-order polynomial relationship between survey dates and the proportion of peak abundance, which our model predicted to occur on 29 March (Fig. 2). Because cranes began arriving in the CPRV prior to surveys (i.e., 15–22 Feb), we extrapolated the abundance model with a linear relation having a starting value of 3% of peak abundance on 15 February and ending value of 8% predicted for the first survey on 23 February. To estimate predicted numbers of cranes present each day, we multiplied an estimated daily proportion by peak abundance for the selected model scenario, specifically 400,000 cranes for the historical model and 510,000 cranes for contemporary models (Reinecke and Krapu 1986, Kinzel et al. 2006). We divided abundance of cranes by sex and subspecies using a 50:50 sex ratio and 36:64 ratio of greater to lesser sandhill cranes over all regions (Reinecke and Krapu 1986; G. L. Krapu, unpublished data). For the historical scenario, we divided cranes into 2 geographical regions in proportions used previously (Reinecke and Krapu 1986). For the contemporary and future scenarios, we used the mean distribution of cranes among 3 regions over 5 years to allocate 8% of the population to the western region, 38% to the central region, and 54% of the population to the eastern region (Kinzel et al. 2006; Fig. 1).

We included energy needs for populations of 5 species of waterfowl, including Canada geese, white-fronted geese, snow geese, mallards (*Anas platyrhynchos*), and northern pintails (*Anas acuta*; hereafter pintails). We followed a procedure similar to the one described above to estimate individual and population energy requirements; however, we calculated metabolic rates using a waterfowl-specific allometric equation (Miller and Eadie 2006). Additionally, we did not explicitly calculate the cost of flight for waterfowl because they roost on the river and in adjacent wetlands in the Rainwater Basin; thus, we were not able to derive daily flight distance as we did for cranes. We used published body mass data for Canada geese and mallards and empirical data collected in south-central Nebraska for white-fronted geese, snow geese, and pintails (Bellrose 1980; R. R. Cox, Jr., USGS, unpublished data; Table 1). Except for white-fronted geese, where historical information was available (Krapu et al. 1995), we used the same body mass and growth parameters in all simulation models. We estimated individual energy requirements by adding the cost of lipid production, if applicable, to $3.0 \times$ BMR (Prince 1979). We selected yearly maximum abundances of waterfowl species from ground surveys and used the median of these values ($n = 5$) to estimate abundance. Although we observed most waterfowl species during all surveys, we defined residency times as the period when most of each species were present. Estimates of temporal abundance and residence times remained constant for all species among model runs except for snow geese, which we assumed did not use the CPRV in the historical model, and Canada geese, which formerly occurred in reduced numbers (USFWS 1981). For Canada geese, we assumed an abundance of 100,000 geese during the 1970s and a residence time of 21 days (G. L. Krapu, personal observation). We used data from the ground transect surveys to estimate chronologies of use and proportional distribution of waterfowl among geographical regions of the study area (Table 1).

Energy availability.—We used 3.90 kcal/g as the true metabolizable energy content of corn for all species (Petrie et al. 1998). We used 205 kg/ha as the estimate of available corn and cornfield area in the region as reported previously by Reinecke and Krapu (1986). For contemporary models, we used estimates of available corn from springs 1998–1999 and 2005–2007 (M. H. Sherfy and M. J. Anteau, USGS, unpublished data). Surveys conducted in 1998 and 1999 after cranes departed provided a surrogate measure of the giving-up density for corn during spring (i.e., amt of corn remaining after individuals abandon foraging sites).

Cornfields occurred within and adjacent to previously defined boundaries of the CPRV (Krapu et al. 1984). For each region, we used spatial data and analyses to quantify area of cornfields as a function of their distance from known roost sites. We used crop data for Nebraska during growing seasons 2002–2004 to correspond with roost-site data collected in the following springs (National Agricultural Statistics Service 2002–2007). After quantifying the area of cornfields near roost sites (Fig. 3), we converted area of fields to mass of corn potentially consumed by multiplying area (ha) times the difference between the available and giving-up masses (kg/ha). The results expressed energy availability as an expected maximum distance from roost sites that individuals would need to travel to obtain food.

Simulations.—We used the bioenergetic model to reproduce historical, contemporary, and future scenarios. We based the historical scenario on data from the late

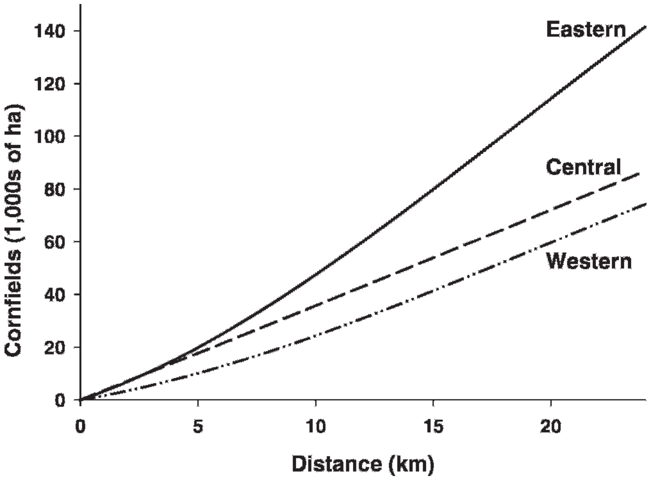

Figure 3. Predicted mean availability of cornfields in relation to distance from active roost sites of sandhill cranes in the eastern, central, and western regions of the central Platte River valley of Nebraska, USA, during springs 2003–2005.

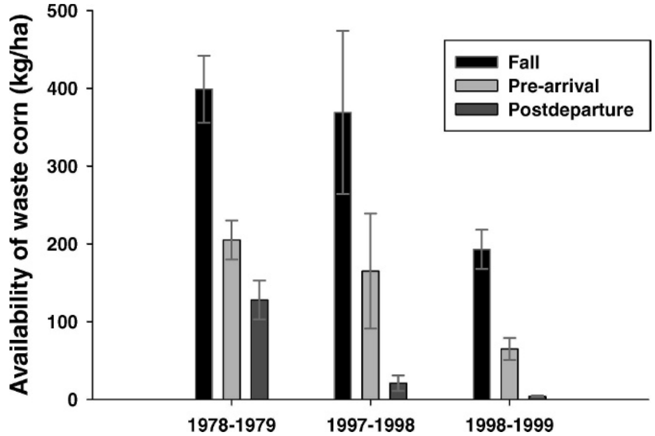

Figure 4. Availability of waste corn (kg/ha; ±1 SE) after harvest (fall), before arrival of migratory sandhill cranes during February (pre-arrival), and after departure of sandhill cranes during April (postdeparture) in the central Platte River valley of Nebraska, USA, 1978–1979 and 1997–1999. Estimates from late 1970s from Reinecke and Krapu (1986) and fall estimates during late 1990s from Krapu et al. (2004).

1970s, except for information, such as spatial and temporal distribution of waterfowl, that was not available. When data were missing, we used contemporary values and assumed they had not changed appreciably. We based contemporary simulations on data collected during 1998–2007. We conducted multiple simulations of future scenarios to compare losses of 25%, 50%, and 75% in availability of corn and cornfield area individually and in combination. Finally, we investigated the influence of variation in snow goose abundance in the region by reporting percentage changes in cornfield area needed to meet the energetic needs of migratory birds under scenarios where snow goose abundance varied from −100% to 200% of abundance used in contemporary simulations.

RESULTS

Corn Availability

We sampled 22 fields before cranes arrived in spring 1998 and 23 fields in 1999. Mean mass of available corn during spring 1998 was 165 kg/ha (SE = 74) and 65 kg/ha (SE = 14) during spring 1999. Corn availability decreased 55% between fall harvest in 1997 and spring 1998 and 66% between fall 1998 and spring 1999 (Krapu et al. 2004; Fig. 4). Corn abundance after cranes departed averaged 6 kg/ha (SE = 1). Within years, corn declined 87% and 94% between arrival and departure of cranes and waterfowl during springs 1998 and 1999, respectively (Fig. 4). For use in our contemporary bioenergetic model, we derived an overall estimate of corn availability of 88 kg/ha using year-specific means from springs 1998–1999 and 2005–2007 (M. H. Sherfy and M. J. Anteau, unpublished data). Specifically, we calculated a weighted average, in which we gave corn availability during spring 1998 half the weight of other years because we deemed conditions leading to this value unlikely to occur at a regular interval (Krapu et al. 2004; G. L. Krapu, personal observation).

Reinecke and Krapu (1986) found that 36,200 ha or 43% of their study area along the Platte River were cornfields. During 2002–2007, the area in corn production within a 3.7-km radius of the main channel of the Platte River varied from 29% in 2003 to 39% in 2006 and averaged 33%, a decrease of 23% from the late 1970s. Soybean production averaged 10,916 ha or 19% of cropland area (10% of total area) between 2002 and 2007.

Sandhill Crane and Waterfowl Surveys

Average distances cranes traveled from river roosts increased through time (Fig. 5). Cranes foraged closer to the river in spring 1998 when we estimated corn was 2.5 times more abundant before arrival than in 1999.

Snow geese represented 72% of total waterfowl abundance in the CPRV, whereas pintails were least abundant, constituting 1% (Table 1). We used 4 weeks of residence time for Canada geese, 3 weeks for mallards and pintails, and 2 weeks for snow and white-fronted geese. Abundance of waterfowl species varied among regions (Table 1). Geese were most abundant in the eastern region (45–47%), whereas pintails and mallards were most abundant in the central region (40–51%).

Population Energetics Simulations

Our historical energetics scenario predicted total energy demand was 11,226 million kcal, with 86% allocated to the eastern region (i.e., staging area 1 from Reinecke and Krapu 1986). Lesser sandhill cranes represented 51%, greater sandhill cranes 31%, and waterfowl 18% of the total. Energy for flight constituted 6% of the total energy required by cranes during spring. We estimated 2,878 metric tons of corn from 14,464 ha of fields was needed to meet this demand. Based on cornfields available during this time, cranes and waterfowl consumed available corn from 46% of fields in the eastern region and 23% of fields in the western region (i.e., staging area 2 from Reinecke and Krapu 1986).

Using contemporary parameters, we estimated total energy need of cranes and waterfowl was 20,975 million kcal over the 60-day period of interest. Lesser sandhill cranes

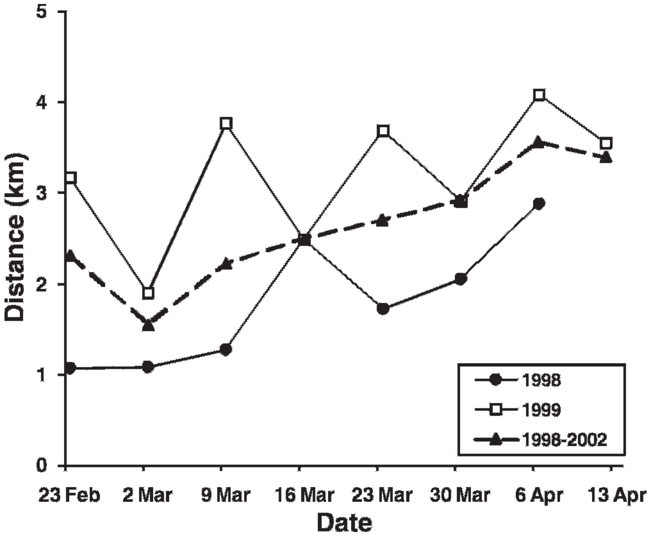

Figure 5. Average distances we observed sandhill cranes from the Platte River, Nebraska, USA, during ground transect surveys in springs 1998, 1999, and averaged over springs 1998–2002.

Table 2. Percentage of energy demand for contemporary model of population energetics of sandhill crane and waterfowl during spring migration in the central Platte River valley, Nebraska, USA, 1998–2007.

	Study area region			
Species or group	Western	Central	Eastern	Total
F lesser sandhill crane	1.9	8.1	7.5	17.5
M lesser sandhill crane	1.9	8.0	7.3	17.2
F greater sandhill crane	0.3	2.4	8.5	11.2
M greater sandhill crane	0.3	2.6	9.0	11.9
Greater white-fronted goose	0.2	0.5	0.6	1.3
Canada goose	4.7	3.6	7.3	15.6
Snow goose	6.2	6.7	11.0	23.9
Mallard	0.4	0.4	0.3	1.1
Northern pintail	0.1	0.1	0.1	0.3
Total	16.0	32.4	51.6	100

represented 35% of the total energy demand, greater sandhill cranes 23%, and waterfowl 42% (Table 2). Cost of foraging flights for cranes was 20% of their energy expenditure. Among waterfowl species, snow geese represented 69% of energy requirements and mallards and pintails the least at 3%. Energy demand differed among regions and among species groups within regions. In the eastern region, energy demand was 1.6 and 3.2 times greater than in central and western regions, respectively (Table 2). Energy demand of greater sandhill cranes was greatest in the eastern region and 71% less in the central region and 97% less in the western region. Lesser sandhill cranes required the greatest amount of energy in the central region and only 24% as much in the western region. Energy demand among species of waterfowl was similar across regions and constituted 73% of total energy demand in the western region (Table 2).

We estimated migratory cranes and waterfowl in the CPRV would consume 5,378 metric tons of corn based on parameters of our contemporary scenario. Using 88 kg/ha as mean availability of corn and 6 kg/ha as the amount left in the field after foraging ceased, cranes and waterfowl required 65,587 ha of cornfields to meet their energy needs. Energy demand in the eastern region was 33,812 ha or all cornfields within 7.7 km of roost sites along the Platte River. In the central region, 21,260 ha of fields within 6.0 km of crane roosts were necessary to meet energy demands, and 10,515 ha of fields with 5.2 km of crane roosts were needed to meet energy demands in the western region. Due to greater availability of corn in spring 1998, only 32,751 ha of fields within 3.0–4.4 km of roosts were necessary to meet energetic needs. In contrast, 90,559 ha of fields within 6.8–9.9 km of roosts were needed to meet demand in spring 1999. Due to reduced flight distances, cranes expended 15% of their energy on foraging flights in 1998 and 22% during 1999.

Potential future decreases in corn availability increased area of fields necessary to meet energy demands and corresponding travel distances. Decreasing corn in existing fields by 25% to 66 kg/ha increased area of fields required by 40% in the eastern region, 39% in the central region, and 41% in the western region. In contrast, conversion of 25% of cornfields to other land uses only increased area of fields required by 2% in the eastern, 2% in the central, and <1% in the western region, but the effect on maximum flight distances was similar to the preceding scenario (Fig. 6). The eastern and central regions were more sensitive to potential agricultural changes and the maximum foraging distance we considered (i.e., 24 km) was exceeded in numerous combinations of declines in each parameter (Fig. 6).

We estimated 15,645 ha of cornfields were required to meet energy requirements of snow geese in the CPRV under average contemporary conditions. Variation in abundance of snow geese had similar impacts in eastern and central regions, whereas the western region was most sensitive to changes in snow goose numbers (Fig. 7).

DISCUSSION

Factors Influencing Availability of Corn

We observed considerable among-year variation in availability of corn during spring in CPRV cornfields. Availability of corn was substantially greater during spring 1998 than 1999, and this difference was due to the large amount of corn present after harvest in autumn 1997 (Krapu et al. 2004; Fig. 4). Corn available before cranes arrived during springs 2005–2007 in the CPRV ranged from 46 kg/ha to 117 kg/ha (M. H. Sherfy and M. J. Anteau, unpublished data). The less striking variation that occurred among springs 1999 and 2005–2007 likely reflected more subtle variation in weather and other harvest conditions that can affect ear loss before harvest or kernel loss during harvest (Baldassarre et al. 1983).

Krapu et al. (2004) observed a long-term negative trend in availability of waste corn after harvest during fall, attributing this reduction mainly to increases in harvest efficiency. We found this pattern continued into spring, wherein corn availability decreased 57% from the late 1970s to the late 1990s and early 2000s. Furthermore, we observed a large increase in the percentage reduction of corn within spring between 1979 and 1998–1999. In the 1970s, corn declined

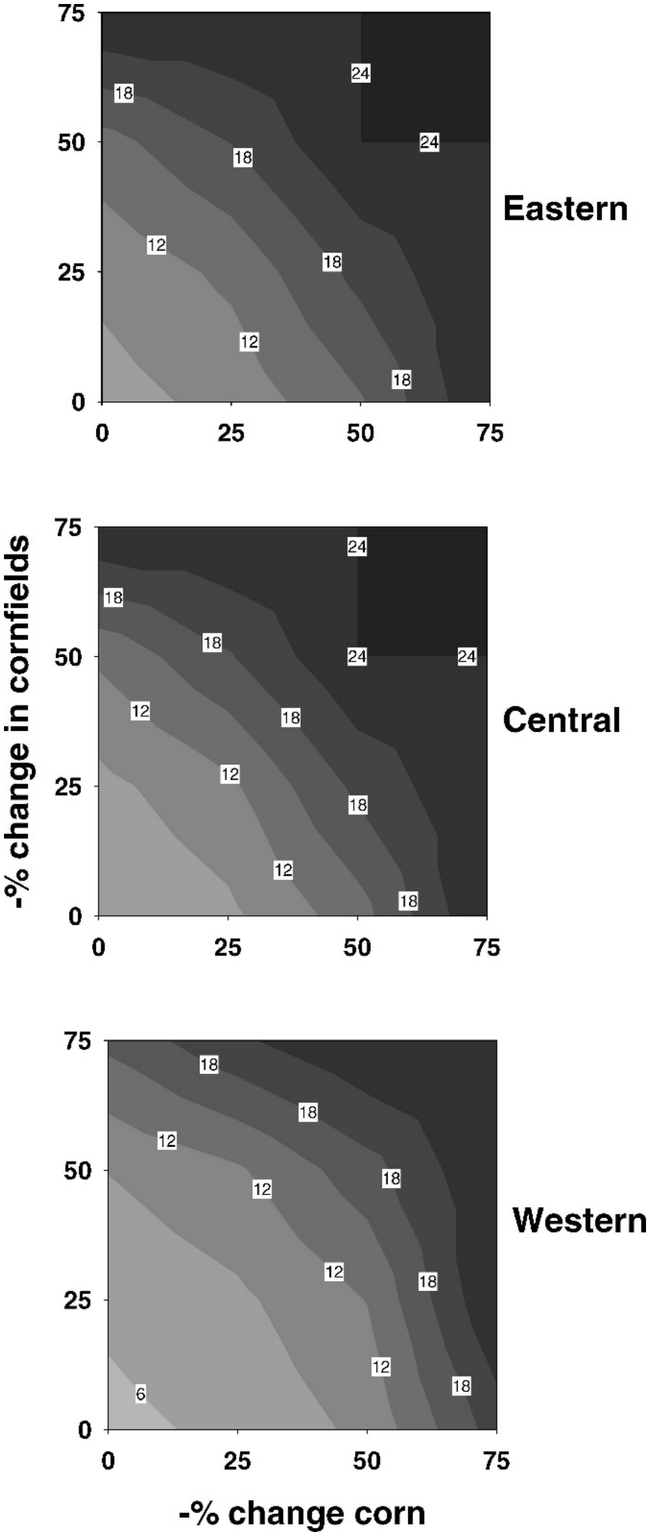

Figure 6. Estimated maximum foraging flight distance (km) of sandhill cranes resulting from different combinations of percent decreases in availability of waste corn and area of cornfields in eastern, central, and western regions of the central Platte River valley, Nebraska, USA.

38% between arrival and departure of cranes and waterfowl, and abundant corn remained after cranes departed the CPRV (Reinecke and Krapu 1986). However, even with near-historic amounts of corn available before arrival of migratory birds in 1998, little corn remained after departure

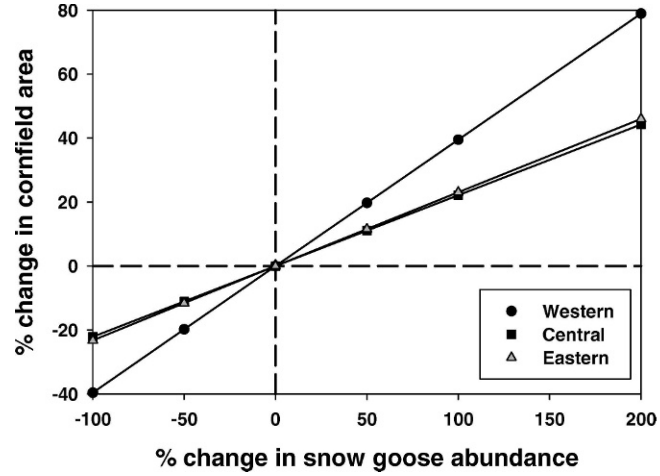

Figure 7. Percentage change in area of cornfields needed to meet energy demand of spring-staging sandhill cranes and waterfowl relative to percentage changes in abundance of snow geese in eastern, central, and western regions of the central Platte River valley, Nebraska, USA.

and losses during spring were $\geq$87%. This disparity provides evidence of increased demand for corn in recent years, and the minimal amount of corn left after cranes and waterfowl departed in spring 1999 suggests intense pressure on food resources in typical years.

Corn production has dominated land use in the CPRV over the past several decades and, when substantial waste grain remained in fields after harvest, provided an abundant food resource and favorable foraging conditions for migrating cranes in spring (Reinecke and Krapu 1986). Corn continued to be the dominant crop in the CPRV during 1997–2006, but soybean production increased from $<$1% of cropland area during the 1970s to approximately 20% by 2005 (Krapu et al. 1984, National Agricultural Statistics Service 2002–2007). This conversion is particularly relevant because cranes and waterfowl largely avoided feeding on soybeans in the CPRV and nutrient content of soybeans is poorly suited for lipid storage (Loesch and Kaminski 1989, Krapu et al. 2004). In the near term, corn production may continue at present levels or expand due to demand for corn-based ethanol and the potential for high corn yields on irrigated lands in the CPRV. However, soybeans may expand in the long term if non-grain sources of biomass replace corn-based ethanol production, as mandated by Congress within the next 20 years (Energy Independence and Security Act 2007). Additionally, rising costs of fertilizers and scarcity of water for irrigation may favor soybean over corn production in the future (Pimentel and Patzek 2005).

Sandhill Crane Carrying Capacity

Availability of corn in contemporary model scenarios caused temporal and spatial variation in carrying capacity among years and geographic regions within years. We estimated a 175% increase in cornfields needed to meet energy demands of migratory birds during 1999 compared to 1998 due exclusively to the difference in availability of corn. Spatially, the eastern region had the greatest demand for energy, and this difference resulted mainly from the unequal distribution of cranes. Differences in crane use resulted from a combination of variation in roosting habitat (Krapu et al. 1982) and distribution of cropland planted to corn. The eastern region contained the most high-quality roosting habitat and cornfields and, consequently, held over half of the crane population. Because of the large number of greater sandhill cranes using the eastern region, energy demands and distance we predicted cranes to travel from roosts to foraging sites were greatest. In contrast, waterfowl dominated the western region and, accordingly, carrying capacity in this region was more sensitive to variation in snow goose abundance than were other regions.

During the contemporary period, >500,000 snow geese used the CPRV and increased pressure on food resources to levels not observed 20 years earlier. This dramatic increase in use of the CPRV by snow geese occurred due to rapid growth of the midcontinent population in the 1990s and a westward expansion of spring migration from the Missouri River valley to south-central Nebraska (Krapu et al. 2005). Status of midcontinent snow geese over the next 10–20 years is uncertain but, given management efforts to reduce population size, any further increase in population size is likely to be less than observed over the past 20 years. However, a stable or reduced population does not necessarily translate into less competition because habitat conditions in the Rainwater Basin and CPRV have a major influence on numbers of snow geese staging in the region (R. R. Cox, Jr., unpublished data).

We used current estimates of crane abundance in our energetic model; thus, our results reflect the current energetic carrying capacity of the CPRV and future trends, given different levels of food availability and competition but a stable crane population. Future management of the midcontinent population of sandhill cranes may benefit greatly from establishment of a population objective that incorporates availability of suitable breeding, staging, and wintering habitats and acceptable levels of harvest. A defined management objective would provide context to the current status of the population and allow crane managers to determine ability of habitats that cranes depend on to meet this objective. Although our model and results cannot be used directly to determine a population objective, results of our contemporary and future scenarios provide indications that a population objective well above the current population abundance may be difficult to maintain if food availability declines in the CPRV. After crane managers develop a population objective, our model could translate that population objective into foraging habitat objectives (Reinecke and Loesch 1996), and these foraging objectives could be used to better inform future decisions regarding if and where management actions should be directed to meet needs of cranes and migratory waterfowl using the CPRV during spring migration.

Potential Consequences of Reduced Forage

During the past 6 decades, the CPRV has proved an exceptional landscape for cranes to stage during spring in preparation for migration to distant breeding grounds and reproduction. Setting model parameters at historical levels, we found carrying capacity of the region for migratory birds was adequate to meet needs within a short distance from the river (≤ 3 km). However, under current conditions, energy availability has decreased due to reduced availability of corn and area of cornfields and, at over the same timeframe, demand for corn has increased because of greater numbers of cranes, snow geese, and Canada geese. Together, these factors increased amount of cornfields needed to meet energy demand by 310% and forced cranes to extend search distances from the river to find profitable foraging sites. Field observations also indicated that cranes foraged farther from roost sites than in the late 1970s (USFWS 1981), and the recent difference in availability of corn between springs 1998 and 1999 was associated with differences in distances traveled to find food.

Although cornfields abound outside of the CPRV, especially south in the Rainwater Basin, there potentially is a physiological maximum distance cranes can travel from roosts in search of forage. Our energetics model predicted that cranes used 20% of their total energy budget for flight, a 3.3-times greater percentage than in the 1970s. Although our model does not provide insight into daily limits on energy expenditure for flight, restrictions on forage distances are likely based on time limitations for searching, consuming, and assimilating food. This barrier would make those cornfields inaccessible to cranes and limit carrying capacity of the CPRV. Furthermore, increased competition for corn from millions of migrating Arctic-nesting geese and ducks exists in the Rainwater Basin as well as risk of avian cholera, which is endemic in that region (Windingstad et al. 1984, Vrtiska and Sullivan 2009).

Midcontinent cranes have benefited from waste corn that allowed birds to deposit large lipid reserves and likely increased survival and recruitment (Krapu et al. 1985). Thus, ability of the CPRV to provide this resource is linked to the health of the population. Data collected in spring 1999, when availability of corn was reduced, indicated some cranes were not able to increase lipid reserves as much as during spring 1998 or the late 1970s when corn was more abundant (Reinecke and Krapu 1986; G. L. Krapu, unpublished data). Corn apparently remained in excess of crane needs in 1998 and allowed birds to maximize lipid storage, whereas in 1999 corn was no longer present at optimal levels for all segments of the population. If available corn were to decline further, major changes could occur in the abundance or physiological condition of cranes staging in the CPRV.

MANAGEMENT IMPLICATIONS

With availability of corn for cranes and waterfowl likely to decline in the future, effective strategies are needed to ensure sufficient availability of energy-rich foods. One option is to encourage dispersal of foraging cranes and waterfowl over a larger cropland base. Availability of suitable riverine habitat for nocturnal roosting limits distribution of cranes in the CPRV (Krapu et al. 1982) and consequently the area where cranes feed on corn. Given that demand by cranes for corn was less in the central and western regions, potential exists to increase carrying capacity of the CPRV by restoring roosting habitat in those regions (Currier et al. 1985).

Among measures that would potentially lessen competition by snow geese include discouraging use of the CPRV by snow geese and encouraging the use of adjacent staging areas including the Rainwater Basin area of Nebraska. Many geese using the CPRV disperse from wetlands in the Rainwater Basin; thus, increasing the number and quality of roosting areas for snow geese in the Rainwater Basin could alleviate competition in the CPRV, with the collateral benefit of providing valuable habitat for other midcontinent waterfowl. However, increased use by snow geese in the CPRV may be linked in part to spring hunting, which leads to increased disturbance of snow geese and other waterfowl in the Rainwater Basin (R. R. Cox, Jr., unpublished data).

ACKNOWLEDGMENTS

We thank the Central Flyway Council, Nebraska Game and Parks Commission, Rainwater Basin Joint Venture, Rainwater Basin Wetland Management District, USFWS–Ecological Services Office in Grand Island, Nebraska, and USGS–Platte River Priority Ecosystems Study for funding and in-kind assistance. We thank M. H. Sherfy and M. J. Anteau for sharing waste-corn availability data in the CPRV. We received assistance during fieldwork from numerous assistants and individuals with the Nebraska Game and Parks Commission (C. Rundstrom, R. Meduna, W. Jobman, D. Carlson, and E. Wilson) and USFWS–Ecological Services Office in Grand Island, Nebraska (J. Runge and M. Schwarz). B. D. Dugger, J. Giroux, W. E. Newton, and K. J. Reinecke reviewed earlier versions of this manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the United States Government.

LITERATURE CITED

Abraham, K. F., R. L. Jefferies, and R. T. Alisauskas. 2005. The dynamics of landscape change and snow geese in mid-continent North America. Global Climate Change 11:841–855.

Alisauskas, R. T., and C. D. Ankney. 1992. Spring habitat use and diets of midcontinent adult lesser snow geese. Journal of Wildlife Management 56:43–54.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlan, and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11:25–31.

Bellrose, F. C. 1980. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, Pennsylvania, USA.

Currier, P. J., G. R. Lingle, and J. G. VanDerwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. Platte River Whooping Crane Critical Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Energy Independence and Security Act. 2007. Energy Independence and Security Act of 2007. Public Law 110–140, 121 STAT 1523. <http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_public_laws&docid=f:publ140.110>. Accessed 14 Jan 2010.

Frederick, R. B., E. E. Klaas, G. A. Baldassarre, and K. J. Reinecke. 1984. A method for sampling waste corn. Journal of Wildlife Management 48:298–303.

Goss-Custard, J. D., R. A. Stillman, R. W. G. Caldow, A. D. West, and M. Guillemain. 2003. Carrying capacity in overwintering birds: when are spatial models needed? Journal of Applied Ecology 40:176–187.

Jones, K. L., G. L. Krapu, D. A. Brandt, and M. V. Ashley. 2005. Population genetic structure in migratory sandhill cranes and the role of Pleistocene glaciations. Molecular Ecology 14:2645–2657.

Kendeigh, S. C., V. R. Dol'nik, and V. M. Gavrilov. 1977. Avian energetics. Pages 129–204 *in* J. Pinowski and S. C. Kendeigh, editors. Granivorous birds in ecosystems. Cambridge University Press, Cambridge, United Kingdom.

Kinzel, P. J., J. M. Nelson, R. S. Parker, and L. R. Davis. 2006. Spring census of mid-continent sandhill cranes using aerial infrared videography. Journal of Wildlife Management 70:70–77.

Krapu, G. L., D. A. Brandt, and R. R. Cox, Jr. 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32:127–136.

Krapu, G. L., D. A. Brandt, and R. R. Cox, Jr. 2005. Do arctic-nesting geese compete with sandhill cranes for waste corn in the Central Platte River Valley, Nebraska. Proceedings North American Crane Workshop 9:185–191.

Krapu, G. L., D. E. Facey, E. K. Fritzell, and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. Journal of Wildlife Management 48:407–417.

Krapu, G. L., G. C. Iverson, K. J. Reinecke, and C. G. Boise. 1985. Fat deposition and usage by arctic-nesting sandhill cranes in Nebraska. Auk 102:362–368.

Krapu, G. L., K. J. Reinecke, and C. R. Frith. 1982. Sandhill cranes and the Platte River. Transactions of the North American Wildlife and Natural Resources Conference 47:542–552.

Krapu, G. L., K. J. Reinecke, D. G. Jorde, and S. G. Simpson. 1995. Spring-staging ecology of midcontinent greater white-fronted geese. Journal of Wildlife Management 59:736–746.

Loesch, C. R., and R. M. Kaminski. 1989. Winter body-weight patterns of female mallards fed agricultural seeds. Journal of Wildlife Management 53:1081–1087.

Lohr, S. L. 1999. Sampling: design and analysis. Brooks/Cole, Pacific Grove, California, USA.

Miller, M. R., and J. McA. Eadie. 2006. The allometric relationship between resting metabolic rate and body mass in wild waterfowl (Anatidae) and an application to estimation of winter habitat requirements. Condor 108:166–177.

Miller, M. R., and W. E. Newton. 1999. Population energetics of northern pintails wintering in the Sacramento Valley, California. Journal of Wildlife Management 63:1222–1238.

National Agricultural Statistics Service. 2002–2007. Cropland data layer. <http://www.nass.usda.gov/research/Cropland/SARS1a.htm>. Accessed 24 Jan 2008.

Norberg, U. M. 1996. Energetics of flight. Pages 199–249 *in* C. Carey, editor. Avian energetics and nutritional ecology. Chapman & Hall, New York, New York, USA.

Petrie, M. J., R. D. Drobney, and D. A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62:1147–1152.

Pimentel, D., and T. W. Patzek. 2005. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Natural Resources Research 14:65–76.

Prince, H. H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 103–117 *in* T. A. Bookhout, editor. Waterfowl and wetlands: an integrated review. Proceedings of the 1977 Symposium of the North Central Section of the Wildlife Society, Madison, Wisconsin, USA.

Reinecke, K. J., and G. L. Krapu. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. Journal of Wildlife Management 50:71–79.

Reinecke, K. J., and C. R. Loesch. 1996. Integrating research and management to conserve wildfowl (Anatidae) and wetlands in the Mississippi Alluvial Valley, USA. Gibier Faune Sauvage, Game and Wildlife 13:927–940.

Reynolds, P. S., and R. M. Lee, III. 1996. Phylogenetic analysis of avian energetics: passerines and nonpasserines do not differ. American Naturalist 147:735–759.

Sharp, D. E., and W. O. Vogel. 1992. Population status, hunting regulations, hunting activity, and harvest of mid-continent sandhill cranes. Proceedings North American Crane Workshop 6:24–32.

Stafford, J. D., R. M. Kaminski, K. J. Reinecke, and S. W. Manley. 2006. Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70:61–69.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1992. Sandhill crane (*Grus canadensis*). *In* A. Poole, editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, NY, USA. <http://bna.birds.cornell.edu/bna/species/031>. Accessed 18 Jun 2009.

U.S. Fish and Wildlife Service [USFWS]. 1981. The Platte River ecology study special research report. U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, ND, USA. <http://www.npwrc.usgs.gov/resource/habitat/plriveco/index.htm>. Accessed 18 Jun 2009.

Vrtiska, M. P., and S. Sullivan. 2009. Abundance and distribution of lesser snow and Ross's geese in the Rainwater Basin and central Platte River Valley of Nebraska. Great Plains Research 19:147–155.

Walsberg, G. E. 1983. Avian ecological energetics. Pages 161–220 *in* D. S. Farner and J. R. King, editors. Avian biology. Volume 7. Academic Press, New York, New York, USA.

Wiens, J. A., and A. H. Farmer. 1996. Population and community energetics. Pages 497–526 *in* C. Carey, editor. Avian energetics and nutritional ecology. Chapman & Hall, New York, New York, USA.

Windingstad, R. M., J. J. Hurt, A. K. Trout, and J. Cary. 1984. Avian cholera in Nebraska's rain-water basins. Transactions of the North American Wildlife and Natural Resources Conference 49:577–583.

Associate Editor: Dugger.